70-24

PRACTICAL PROBLEMS IN THE DESIGN OF FIELD EXPERIMENTS

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Consideration of the basic principles of experimental design as well as the selection of statistical methods for data acquisition and analysis is mandatory in the planning phase of any experiment. This is true whether it is to be performed in the laboratory or in the field.

There are certain differences, however, between laboratory and field research which must be considered in the formulation of a field research program. These differences primarily result because the environment is beyond control of the researcher. However, of almost equal concern are the management problems, particularly personnel, that occur in the field. If these factors are not recognized and considered in the experimental design as possible sources of variation, their effects will most certainly be confounded with the response of the material, condition, or property under investigation.

This confounding of the effects of uncontrolled variables with controllable and measured parameters under test will not only produce invalid quantitative data, but due to possible interaction between these effects, statistical tests may erroneously indicate that significant differences are occurring for the conditions being investigated. In reality, however, these differences may be insignificant. Usually, the effect of this sort of confusion is to limit the ability to detect changes in test parameters when they do occur.

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A. Two Basic Categories of Field Experiments

At this point, a look at two basic categories ot highway field research is in order. The first category includes those experiments where the uncontrolled variables are largely confined to the intrinsic properties of the natural environment. Typical experiments might range from weathering of paints or signing materials to in situ testing of rock or soil for evaluation of new test devices. This category of experiment is usually characterized by a relatively relaxed time schedule and the fact that the investigator has direct control over project labor, administration, and progress. Many such projects are relatively inexpensive and most can be repeated with little deleterious change in the uncontrolled variables or increase in cost.

The second basic category encompasses those projects which are associated with the construction of a highway facility or appurtenance. Typical work in this category might range from the instrumentation of an orthotropic bridge for observation of stress patterns to the measurement of pore pressure variation in a soft foundation due to embankment construction. Experiments in this category are often characterized by dependence on a contractor's time schedule and the investigator's lack of direct control over project labor, administration, and progress. Such projects may be quite expensive and are usually impossible to repeat because the uncontrolled variables are unique to the particular location or structure and redoing an entire structure or even a portion would be prohibitively expensive.

It is evident that research falling in this second basic category will require a greater "safety factor" due solely to the irretrievable nature of the experiment. By a greater "safety factor" I mean, for example, one or two levels of redundancy for critical data points to guard against data loss due to failure, enable better statistical averaging, and provide better application of tests for significance.

Some of the other problems occurring in this type of research are primarily administrative in nature. These administrative problems, however, do affect the design of the experiment. The effects are mainly financial and psychological. The psychological effects will be mentioned later under human factors as uncontrolled variables. From a financial standpoint, the administrative nature of such a project causes an excessive expenditure of research money. This money is needed not only for extra instrumentation but also for the extra man-hours for "standby time" to match the schedule imposed by the contractor or weather.

Provisions for adequate working time to install the research facilities, physical help from the contractor's personnel, and subsequent protection of the research facility from the contractor's operations are a necessary part of the contract. The lead time for this type of research is, therefore, substantial and must be considered in the early planning stages.

Once the contract is let, prosecution of the research is greatly facilitated by conferring jointly with key personnel of the contractor and the project engineer. Administrative problems such as work sequence, payment for extra work, and joint and individual responsibilities can be worked out. Some of the actual physical steps in the research should be kept flexible up to this point to allow incorporation of ideas which may be presented by the other conferees. If the researchers earnestly seek to enlist the cooperation and interest of these people, the research will be greatly aided. Research personnel who like to project an "ivory tower" image will be a detriment to this sort of conference.

An often justifiable expense for field experiments in this second category is the employment of a field coordinator for the research. This individual should be selected from the highway project personnel. He acts as a go-between for the researchers and both contractor's and project personnel once the project is underway. Mandatory personal attributes include statesmanship, an appreciation for research, a well-developed sense of humor, and an excellent knowledge of construction practice. Such a person can be worth many times his salary in smoothing the path for research personnel.

During the progress of the research, both the project engineer and the contractor should be kept informed of significant and interesting developments. When the report is written, acknowledgment of their assistance should be made and they should receive copies of the report. Recognition of this sort will go a long way toward improving both present and future research climate.

B. The Nature of Uncontrolled Variables and Other Problems

Uncontrolled variables affecting either or both of the two basic types of field experiments will normally fall into one of four general groups including environmental factors, human factors, hardware factors, and construction methods. Obviously, all of these variables will not apply to all field experiments and, in many cases, there will be considerable interrelationship between variables.

Some of the problems, such as accidental or malicious damage to the experiment, can't be dealt with statistically as can the unknown or uncontrolled variables. These problems must be considered, however, in planning the experiment.

1. Environmental factors are normally uncontrolled or only partially controlled in most field research. Included in this general group are such obvious things as temperature, relative humidity, wind, vibration, anisotropy of soil deposits, and corrosive atmosphere or water. Also in this group are less obvious but diverse factors such as damage to the experiment due to falling rock or earth slope failures, biological damage to instrumentation, changes in water table due to pumping or irrigation and changes in geometry with increase in fill height. These are just a few examples.

2. Human factors are constantly with us. In field research the investigator may have to consider the ability or desire of a craftsman to build a facility to the tolerance required for the experiment. Conversely, tighter tolerances than normal may be obtained due to presence of a research observer.

When the progress of the work is controlled by a contractor's operation, research personnel are often placed under stress because of unpredictable variations in the time schedule. Also, research which is part of such a highway contract is often a "poor relation" in the eyes of project and contractor's personnel. Morale and efficiency of the research team suffer as a result. These and other similar psychological factors have a direct bearing on the reliability of the acquired data.

Adverse working conditions such as rain, snow, and mud will doubtless have their effect on the efficiency and performance of the researchers.

Often the nature of the field experiment requires considerable assistance from nonresearch oriented personnel. In these cases, communication, or rather the lack of it, can lead to invalid data. Careful selection of research personnel and assistants is indicated. In addition, enthusiasm for the project must be instilled in everyone involved.

Vandalism can be a nightmare to the researcher in the field. An average marksman with a small caliber rifle can reduce an unprotected installation to junk within minutes. Careless exposure of copper and other marketable materials may encourage surreptitious salvage operations.

3. Hardware factors should be evaluated prior to the data acquisition stage. Instrumentation should be designed for system accuracy and repeatability which does not deteriorate under field conditions. Suitable backup for critical data acquisition methods must be provided.

Experiments with complex instrumentation may require automatic data acquisition equipment. Precautions for on-the-spot maintenance and backup must be taken. Power must be reliable. In some cases, such complex projects entail considerable expense for the physical appurtenances necessary for adequate data acquisition.

The inability to anticipate the magnitude of error inherent in a field measurement technique may invalidate the data. Inherent error of an inappropriate measurement technique may approach or exceed, in magnitude, the change in the test parameter.

Some of these considerations may seem quite basic, and they are, but it is surprising how often they may be overlooked.

4. Construction methods which constitute accepted highway practice must be considered in research design. The investigator can expect to encounter resistance if he proposes new methods entailing the use of nonstandard equipment or unfamiliar methods. Shoddy workmanship is likely to result unless adequate preparation is made, by inclusion of new methods, procedures, and requirements in the contract.

C. Design Compensation for Uncontrolled Variables

1. "Control" sections, or sites, are often included in a test area to isolate and evaluate the source or cause that may have an influence on the response of the material or condition being investigated. The number of control sections may be limited by economic considerations but ideally should be distributed or selected at random throughout the test area, dependent upon the variability of the effects to be isolated. Although the main test parameter is normally held at a single

level for all control sites, additional control sites with the test parameter at other levels should be considered if there is reason to believe an interaction exists between it and uncontrolled sources of variation.

2. Measurement of the magnitude of a known uncontrolled variable and compensation for its effect may sometimes be successful. The compensation may be applied theoretically if there is known to be good correlation between the variable and its effect on the experiment. Usually, however, an empirical correlation is established. In most cases, it is advisable to perform "pilot studies" in preparation for a full-scale field investigation. In this manner, certain conditions which cannot be controlled in the field may be synthesized in the laboratory to determine if these "uncontrolled" conditions either cause predictable results or significantly affect the purpose of the research. Although pilot tests in the laboratory will result in pseudo data values which may or may not be the same as those found in a field investigation, the information obtained can be quite valuable when designing the field experiment.

3. Statistical averaging through replication of instrumentation or data acquisition within test sites, replication of test sites within an area, and replication of readings by different observers or equipment should be considered. Replication and randomized treatment provide a means to determine the reliability of acquired data and will tend to

negate certain uncontrolled variables which are dependent on the site, operator, or equipment and will allow statistical treatment of them in the analysis.

4. Factorial design using analysis of variance principles allows greater efficiency in the use of observations and enables greater precision with less replication than the classical experiment. Random sequences of observations relegate the effects of certain uncontrolled variables to the residual or error term where they are not confused with the test parameters and their contribution to experimental variation can be estimated. With the advent of greater computer usage, analysis of variance technique is applicable to larger, multivariable investigations.

D. Summary

In summary, there are four inseparable phases that must be carefully considered in any good field experiment. These are experimental design considering statistical implications, execution of the field experiment, analysis of data, and implementation of findings. Of these, the initial planning and design phase is almost invariably the most critical. The damage resulting from a poor design is irreparable; no matter how ingenious the analysis, little meaningful information is ever salvaged from data derived from poorly planned experiments. On the other hand, if the design is sound, then even "quick and dirty" methods of analysis can yield a great deal of useful information. It might be stated that the need for careful planning and design of field experiments is even more acute than for laboratory experiments. The additional cost of doing field work, and the need for working with individuals who are not normally associated with research work, makes it imperative that all phases of the work are carefully planned and coordinated. The experimental design procedures which are commonly accepted in laboratory work must be extended into field operations if the results are to be meaningful. In the California Division of Highways we have learned many of these lessons the hard way, primarily through experience. However, through training programs and the influx of engineers over the past several years with formal training in statistics and experimental design, it is now routine to fully consider all the essential elements of experimental design including statistical considerations from the inception of a research project to its culmination in a better highway project.